Indicators of hemeroby for the monitoring of landscapes in Germany

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A B S T R A C T

The article discusses the concepts of "closeness to nature" and "hemeroby", and outlines a method to establish two indicators of hemeroby. Until now Germany's national land use monitoring systems have lacked an indicator to capture the naturalness respectively hemeroby of the landscape. Based on digital spatial data on land use (DLM-DE) and the mapping of potential natural vegetation, these indicators have now been estimated for the whole of Germany and illustrated cartographically. The indicators have been integrated into a land use monitoring system (IOER-Monitor). A hemeroby index that considers all hemeroby classes of a reference area (e.g. administrative unit and regular grid cell) is presented as well as an indicator named "Proportion of certain natural areas". The results on hemeroby of several time-cuts can be used to estimate the cumulative impact of land use changes on the environmental status

K E Y W O R D S

Closeness to nature; Hemeroby index; Human impact on the environment; Land use change; Landscape indicator; Naturalness; Potential natural vegetation; Spatial planning

Introduction

The sealing of surfaces and the intensification of land use around the world results in a decrease in nature accentuated surfaces. This undermines the preservation of biodiversity while potential landscape functions are also impaired, for example the attractiveness of the landscape for nature-based recreation (Dramstad et al. 2006).

For nature conservation, environmental planning and management information about the state of landscape is necessary and changes should be monitored. In accordance with Hellawell (1991) we regard monitoring as "intermittent (regular or irregular) surveillance carried out in order to ascertain the extent of compliance with a predetermined standard or the degree of deviation from expected norm" (s.a. Dröschmeister 2000). Besides the regularly recording of land use data, an evaluation method and appropriate indicators are needed.

Existing national indicator systems reflect the development of land use mainly by describing changes in settlement and traffic areas (e.g. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2007; Federal Statistical Office of Germany 2012). However, these take no account of the quality of land use or how the landscape as a whole has changed. The indicators of hemeroby presented in this contribution should help to provide more informed answers to these questions. We also look at whether the proposed indicators are suitable for a nationwide, regular monitoring scheme in Germany, specifically the IOER-Monitor (www.ioer-monitor.de) which looks at the settlement and development of open spaces. Furthermore, we discuss whether the changes in the landscape condition revealed by these indicators could serve as a basis for recommendations in the field of spatial planning.

Our objectives are in detail:

- the development of indicators of naturalness/ hemeroby of landscapes;
- the evaluation of suitable databases;
- the evaluation of suitable reference units;
- and the integration of indicators of naturalness/ hemeroby in a nationwide regular monitoring scheme.

Hemeroby and closeness to nature

The concept of hemeroby was originally developed for measuring human impacts on flora and vegetation. The term hemeroby, which was introduced by the botanist Jalas (Jalas 1955), is derived from the Greek words hémeros (tamed, cultivated) and bíos (life). Later this concept was applied on whole ecosystems (Blume & Sukopp 1976: p. 83; Sukopp 1972: p. 113ff). According to this, hemeroby can be understood as an integrative measure of the impact of all human intervention on ecosystems (Kowarik 1988; Sukopp 1976: p. 21).

In analysing current forms of land use in regard to human impact, hemeroby measures the distance between the current vegetation and a constructed final state of self-regulated vegetation in the complete absence of human intervention (so called potential natural vegetation (PNV)). Hence, it is as an inverse measure of the closeness to nature, if anthropogenic interventions are reversible (Kowarik 2006: p. 8). The concept of "closeness to nature", in contrast, takes the original natural vegetation as a reference (Kowarik 2006: p. 4, see Fig. 1). While the original natural vegetation rep-resents the reconstructed vegetation which existed before the settlement of man, PNV describes the vegetation that would appear naturally if human impact is removed (Tüxen 1956). The concept of

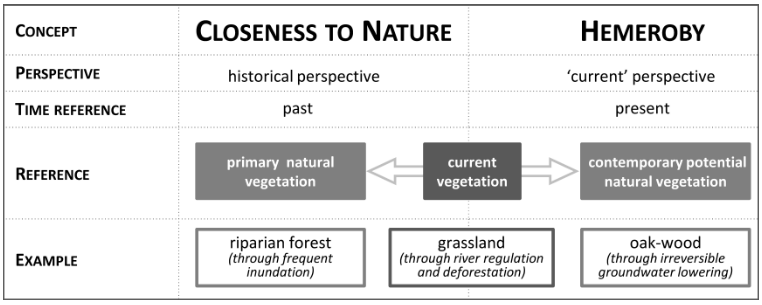

Fig. 1. Comparison of the concepts of closeness to nature and hemeroby. Source: Stein and Walz (2012: p. 262), modified.

hemeroby looks at the current situation and, because it takes into account irreversible changes to the site in its reference to the PNV, describes the likely site potential (Jedicke 2003: p. 29). All in all, hemeroby and closeness to nature can be considered as two separate concepts to describe naturalness. Only if irreversible changes to the site happen, there will be different results.

In principle, the classification of closeness to nature or hemeroby can be made at the type level of habitat or land use classes (see also Kowarik et al. 2008: p. 76). For this purpose several scales of hemeroby can be found in the literature (Kowarik 2006: p. 9; Sukopp 1969: p. 363).

Mapping of hemeroby at regional and national level

The concept of hemeroby can be used to evaluate and compare landscapes. It enables an assessment and temporal comparison of landscape in which relative changes over time are more important than absolute values (Peterseil et al. 2004). Hitherto hemeroby has been mostly applied to smaller clearly defined areas, individual cities (e.g. Cscorba & Szabó 2009; Jedicke 2003; Kieser & Thannheiser 2001; Konnert & Siegrist 2000; Steinhardt et al. 1999) or regions (LfULG 2009; Schlüter 1992; Stein & Walz 2012). The concept has also been applied to the Federal Republic of Germany by using CORINE Land Cover data (Glawion 2002) to classify various land uses into spatial types and assigning a degree of hemeroby. Because of the underlying classification into only 16 spatial types and the relatively small scale, this mapping, while providing a general overview, is inappropriate for a more accurate calculation of spatial extent and thus the monitoring of local and regional developments.

For the European Union, Brentrup et al. (2002) have suggested to adopt the concept of hemeroby for analysis of the environmental impact of land use changes on the basis of bio-geographical regions. Only recently a proposal was presented for the integration of an indicator on naturalness into the agri-environmental set of indicators at the European level (Paracchini & Capitani 2011). Machado (2004) presented a well considered plan for the implementation of the concept of naturalness in the Galapagos Archipelago, the island of El Hierro and a section of the Canary Islands. A map of hemeroby for an entire country, in this case Austria, was created by the SINUS Project Team (Peterseil et al. 2004; Wrbka et al. 2004) and Rüdisser et al. (2012). Previously Grabherr et al. (1998) mapped the hemeroby of the Austrian forest ecosystems. In South Tyrol Tasser et al. (2008) determined hemeroby, among other indicators of biodiversity, on the basis of land use data and surveys of the vegetation. In the Chinese province of Shaanxi, Fu et al. (2006) have used the concept of hemeroby to assess the sustainability of agriculture in the local Loess hilly region.

Methods

Comparison of possible nationwide data basis

Suitable digital databases for a nationwide evaluation of hemeroby in Germany are the CORINE land cover dataset (EEA2000), the Base-Landscape Model (Basis-DLM) of the Authoritative Topographic–Cartographic Information System (ATKIS) (Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany 2009) and the Digital Land Cover model for Germany (DLM-DE) (Arnold 2009) (see Table 1).

CORINE Land Cover (CLC) is a project of the European Commission for the uniform classification of the main types of land use and land cover in Europe. The digital, mostly automatic, mapping is based on 13 main classes, which are subdivided according to the type of land cover (in particular forms of agriculture) into 44 standard classes for the whole of Europe. Of these, 37 classes of land cover and use are found in Germany. To date three surveys have been carried out: for the years around 1990, 2000 and 2006.The lower limit for the detection of planar elements is a size of 25hectares; for linear elements (e.g. watercourses) there is a minimum width of 100 m. In successive stages of data capture, changes of 5 ha and above have been recorded (Keil et al. 2010). Although CLC data has the advantage of European comparability, the low resolution of detection prevents a detailed assessment of hemeroby.

The Authoritative Topographic–Cartographic Information Sys-tem (ATKIS) is a national standardised system of the Surveying Authorities of the States of the Federal Republic of Germany for the digital recording and display of information on the use and topography of the earth's surface in Germany. The Basis-DLM of ATKIS has the advantage that data is largely homogeneous for the entire country and regular updating is legally assured (Schumacher & Meinel 2009). In the basic update all objects are checked in a frequency of 3–5 years and adjusted for change. Particularly important topo-graphic objects (especially in the field of transport) are updated every 3–12 months. Moreover, it is the latest and most detailed

Table 1
Data sources for the calculation of landscape hemeroby.

Name	Scale	Legend	Latest data from	Updating	Coverage	Characteristics
ATKIS Basis-DLM	1 : 25,000	More than 155 feature types, additional differentiation by further attributes	2012	> 4 years	Germany	
DLM-DE	> 1 ha	37 classes	2009	5 years (planned)	Germany	No linear elements
CORINE land cover	1 : 100,000	14 classes, of which 37 relevant to Germany	2006	6-10 years	Europe	
Potential natural vegetation						
Potential natural vegetation	1 : 500,000		2010	No updating planned	Germany	Reference data

topographic spatial dataset covering the whole of Germany (Meinel 2009). The objects which are included (e.g. linear elements, such as roads, or planar, such as settlement areas, vegetation and water surfaces) are defined in an object catalogue, which includes more than 155 feature types with additional distinguishing attributes (Federal Agency for Cartography and Geodesy 2011). Regarding areas of open space the data is thematically rather less differentiated and also subject to the lowest frequency of update.

By contrast, the DLM-DE dataset offers vector data conforming to the standard European CORINE nomenclature. For the creation of the dataset appropriate land use classes were selected from ATKIS (99) and updated by the interpretation of remote sensing data (RapidEye; DMC – Disaster Monitoring Constellation, see www.dmcii.com). Furthermore, additional information was gained from topographic maps, digital orthophotos or older satellite images. The lower limit of detection is one hectare, which lies between ATKIS (0.1–1 ha) and CORINE (25 ha). Thus DLM-DE constitutes a more detailed and more topical dataset for Germany than CORINE. A first evaluation on the basis of data from 2009 was completed in 2011, and is available from the Federal Agency for Cartography and Geodesy (BKG). A continuous updating of DLM-DE is planned, probably in a 5-year cycle.

Adaptation of data basis

For the purposes of this study, the land use data from the "Digital Land Cover Model" (DLM-DE) was selected as it is more detailed and topical than ATKIS, particularly in the open space categories (forest, grassland). In addition, comparability to both CLC and ATKIS data is ensured. However, since the DLM-DE contains no linear elements, the buffered road and street network and the linear waterways from ATKIS were overlaid onto DLM-DE data. For the buffering of objects such as roads, main rural roads, rails and rivers, which are represented by linear vectors in the Basis-DLM, it was possible to make use of width values also contained in the ATKIS database. If no width data was available, a standard value was derived from related characteristics such as the number of lanes or tracks, or the type of road. Rows of trees and hedges as well as individual trees were disregarded.

Our research showed, that generalisations must be accepted, such as in the classification of forests. Thus the map of the potential natural vegetation (PNV) for Germany only exists at the scale 1:500,000 (BfN 2010). Despite this lack of detail, the database appears sufficient to examine the accordance of the forests of the DLM-DE with their location. We had to generalise the PNV into three classes because the forests of DLM-DE are mapped into three classes as well, while the geometry of the DLM-DE remains unaffected. At most, errors caused by the two different scales of DLM-DE and the PNV-map can occur in the case of fuzzy assignment of ahemeroby degree to objects at a border between different classes of potential natural vegetation. However, this affects only objects within different forest classes and natural forest-free sites.

Classification of hemeroby

A seven-point scale was used to classify land use by degree of hemeroby (Table 2). Such a scale is commonly adopted in the literature (Blume & Sukopp 1976; Glawion 2002; Marks & Schulte 1988) and comparability with other studies is thus ensured. Any finer gradation of the scale of classification on the basis of the DLM-DE would in any case have no additional informational value since the differentiation of forests and open land in the data model is not adequate. For example it is not differentiated between extensive and intensive grassland.

The assignment of a land use class to a special degree of hemeroby respects the intensity, duration and range of human impact (Sukopp 1969). While for example residential areas are characterised by a high degree of soil sealing, which has high impacts on ecological function, and is mostly of long duration, agricultural and forestry areas contain different intensities of use. Thus, for the classification of the hemeroby of forests and areas without any vegetation, an additional intersection with the "Potential natural vegetation" (PNV) was necessary. This required some analysis of the national map of PNV in the present scale of 1:500,000 (BfN 2010). Since forests cover 31.6 % of Germany's total land surface (see www.ioer-monitor.de), a realistic assessment of the human impact on forests was carried out. Forests and areas without vegetation were therefore classified by the extent of their deviation from the potential natural vegetation. A montane spruce forest in the high altitudes of the central uplands or a scree slope which accords closely with the typical PNV for such a site was assigned to a lower hemeroby degree (i.e. weaker human impacts) than a non-native coniferous forest in the lowlands or a human-made gravel surface. Areas that are without human impacts (Marks & Schulte 1988) are described as "ahemerobic". As some degree of human impact exists almost everywhere due to supraregional pollution emissions and climate change, there should be practically no ahemerobic areas in Central Europe (Kowarik 2006). Therefore only potentially natural areas without vegetation (e.g. rock) were assigned to the "ahemerobic" degree (see also Paracchini & Capitani 2011, p. 8; Rüdisser et al. 2012). For the analysis, a semantic generalisation of the basic land use types of the DLM-DE (deciduous, coniferous and mixed forest and natural forest-free sites) was performed.

Table 2
Assignment of CORINE Land Cover classes (CLC) of the DLM-DE to degrees of hemeroby (compilation on the basis of Blume & Sukopp 1976; Glawion 2002; Marks & Schulte 1988; Rüdisser et al. 2012).

Degree of hemeroby	CLC-code and CLC-class of the DLM-DE
1 ahemerobic – almost no human impacts	332 Bare rocks 335 Glaciers and perpetual snow
2 oligohemerobic – weak human impacts	311 Broad-leaved forest 312 Coniferous forest (PNV) 313 Mixed forest (PNV) 331 Beaches, dunes, sands 411 Inland marshes 412 Peat bogs 421 Salt marshes 423 Intertidal flats 521 Coastal lagoons 522 Estuaries 523 Sea and ocean
3 mesohemerobic – moderate human impacts	312 Coniferous forest (not PNV) 313 Mixed forest (not PNV) 321 Natural grasslands 322 Moors and heathland 324 Transitional woodland-shrub 333 Sparsely vegetated areas 334 Burnt areas
4 β-euhemerobic – moderate-strong human impacts	141 Green urban areas 231 Pastures 243 Land principally occupied by agriculture, with significant areas of natural vegetation 511 Water courses 512 Water bodies
5 α-euhemerobic – strong human impacts	142 Sport and leisure facilities 211 Non-irrigated arable land 221 Vineyards 222 Fruit trees and berry plantations 242 Complex cultivation patterns
6 polyhemerobic – very strong human impacts	112 Discontinuous urban fabric 131 Mineral extraction sites 132 Dump sites 133 Construction sites
7 metahemerobic – excessively strong human impacts – biocoenosis destroyed	111 Continuous urban fabric 121 Industrial or commercial units 122 Road and rail networks and associated land 123 Port areas 124 Airports

Indicators of hemeroby

With the help of the first proposed indicator at landscape level – the "hemeroby index" – the human impact for the individual territorial unit (e.g. a municipality) can be summarised and described, allowing us to compare different spatial units or, by using multiple time series, to document the development of hemeroby. To calculate the index, the area-weighted average of all hemeroby values of a landscape is calculated. Such a hemeroby index is already widely used, generally normalised to 100 (Formula 1a) (Frank et al. 2012; Fu et al. 2006; Steinhardt et al. 1999; Tasser et al. 2008). In our opinion the results are confusing, because for a seven-point scale the mean value can lie between 14.3 and 100. Such values are not as easy to interpret as the degrees of hemeroby shown in Table 2. Because of this, we simply calculated the area-weighted mean value of the degrees of hemeroby (Formula 1b).

Formula 1.
Normalised area-weighted hemeroby index (a) and simple areaweighted hemeroby index (b).

a) Normalized area-weighted hemeroby index (Steinhardt et al. 1999)

$$M_1 = 100 \sum_{h=1}^{n} \frac{f_n}{n} h$$

b) Simple area-weighted hemeroby index

$$M_2 = \sum_{h=1}^{n} f_n * h$$

n – Number of degrees of hemeroby (here: n = 7)
f_n – Proportion of category n
h – Degree of hemeroby
M – Hemeroby index

The hemeroby index we present can have a value of between 1 and 7. The latter maximum value corresponds to a fully sealed area classified as metahemerobic, while the minimum value 1 describes an area which corresponds perfectly to the potential natural vegetation cover and thus is classified as ahemerobic.

For the purposes of nature conservation, however, nature-accentuated areas with a degree of hemeroby from ahemerobic to mesohemerobic are of special interest, because these are subject to little or infrequent human intervention. These include site-specific and non-native forests, woodlands and hedgerows, marshes and swamps. It is proposed to calculate the proportion of these nature-accentuated areas to the reference area as a second separate indicator.

The method for calculating these two indicators was thoroughly tested in Saxony (see Stein & Walz 2012) and later adapted for nationwide calculations. Beside the simplification of the formula (see above) it proved necessary to keep the large amount of data to a manageable size. Thus unpaved roads and tree rows were ignored, since inclusion of these linear elements imposes a high computational effort. In addition, watercourses were not classified according to the water structure, but uniformly as β-euhemerobic (Marks & Schulte 1988; Steinhardt et al. 1999). Watercourses could indeed be distinguished by water policy or shipping category, but no national data is available for smaller waters.

Overall, for Saxony it has been found that the simplifications lead to a substantial acceleration in calculation without changing the results in any significant fashion (Stein 2011: p. 92). For example, disregarding tree lines and paths resulted in only a marginal change in the degree of hemeroby for most municipalities.

Reference units

Administrative units (municipalities) and regular grid cells were used as a means of spatial reference. While the land area of municipalities varies in size, and therefore the calculated indicators must always be considered as values relative to this area, the use of grid cell avoids the ambiguity of results based on different reference units. Moreover, the map representation provides a uniform level of detail, while the delineation at the level of local or county borders depends on the size of these units, resulting in a more or less detailed image. In addition, a comparison over time is often hampered by shifting administrative boundaries.

Grid maps are gaining in importance since Eurostat guidelines (European Commission & Eurostat 2005) and INSPIRE specifications (INSPIRE 2010) promote their use. Advantages are mainly their spatial and temporal comparability (without complicated conversions) compared to the exclusive use of administrative territorial units as a reference base (Wonka 2009).

Results

Classification of landscape hemeroby

Assigning degrees of hemeroby to the land use classes leads to a spatially explicit, detailed presentation of hemeroby (Fig. 2). The map sections, showing different regions in Germany, give an idea of the diversity of human impact on landscape. They also confirm the exact assignment of hemeroby to the various land use types.

Hereinafter indicator values are aggregated for spatial reference units.

Indicators of hemeroby and proportionate share of nature-accentuated areas

Although the strength of human impacts in a region can be determined in general from the hemeroby index, no information is given on the actual composition of the area out of single patches with different hemeroby degrees. For example, an index value of 3 will be obtained if the entire area of a municipality is mesohemerobic, but also if the municipality is equally composed of oligo- and β-euhemerobic areas.

On the one hand, the derived maps clearly show the distribution of municipalities with high proportions of nature-accentuated areas (Fig. 3, left). These are often located in upland and mountainous areas, but also on the coast and in the former glacial areas of the North German lowlands. On the other hand, the hemeroby index gives the average values for the municipalities (Fig. 3, right). Here we particularly note municipalities with a high proportion of settlement areas, while intensively farmed areas such as the fertile plains with loess-rich soils (termed “Börden”) are also prominent.

A comparison of indicators between the federal states shows that those which contain mountainous areas (e.g. Rhineland-Palatinate, Hesse, Bavaria) have the largest number of municipalities showing especially low degrees of hemeroby and high shares of nature-accentuated areas. But also Brandenburg, which in comparison to more densely populated (e.g. North Rhine-Westphalia) and agrarian states (e.g. Saxony-Anhalt) has a relatively small population and industrial density, shows a lower human impact.

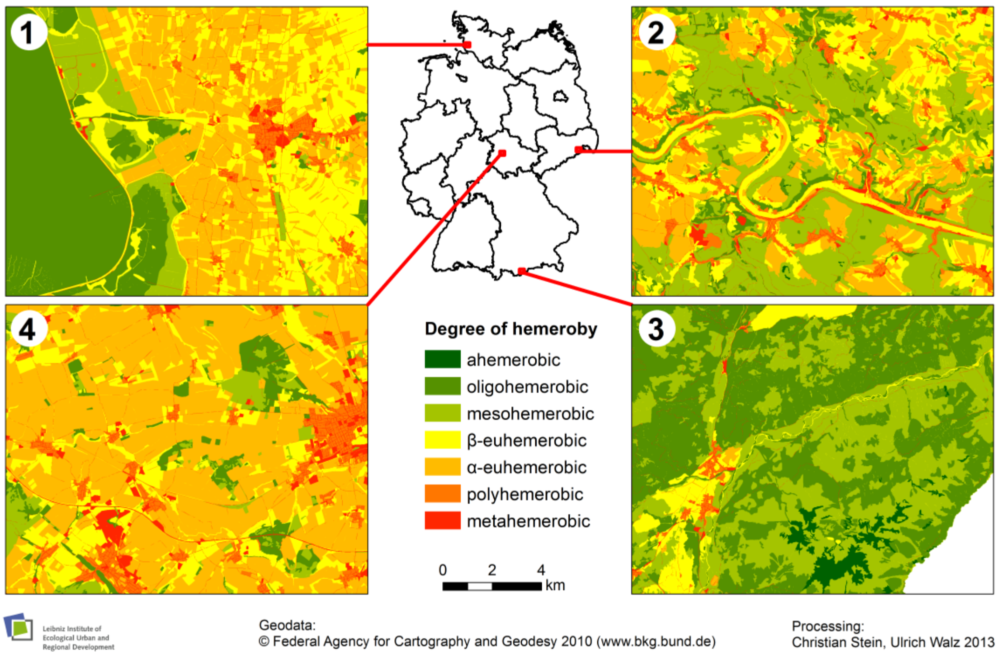

Fig. 2. Landscape hemeroby (sections from various landscapes: North Sea coast (1); Saxon Switzerland (2); Alps (3); and, Thuringian Basin (4)) (editors: C. Stein and U. Walz).

It can be assumed that the average size of municipalities also influences the calculation of indicator values. Rhineland-Palatinate, in particular, is dominated by many small municipalities, leading to a much lower spatial generalisation of results. In larger municipalities, by contrast, the likelihood increases that the mean indicator value encompasses diverse land use types, such as areas in a more natural state (e.g. in the outskirts of settlements) along-side areas within the settlement itself which show a high degree of human impact. In addition, only one value is calculated for each municipal area. On this basis it is impossible to make a more refined analysis of indicators, and thus only one value can be generated for the city-states of Berlin and Hamburg (see Tables 3 and 4). In order to prevent the size of investigated areas from affecting the calculations and to allow further spatial differentiation below the level of municipalities, we also derived indicators on the basis of regular grid cells (see also Fig. 4).

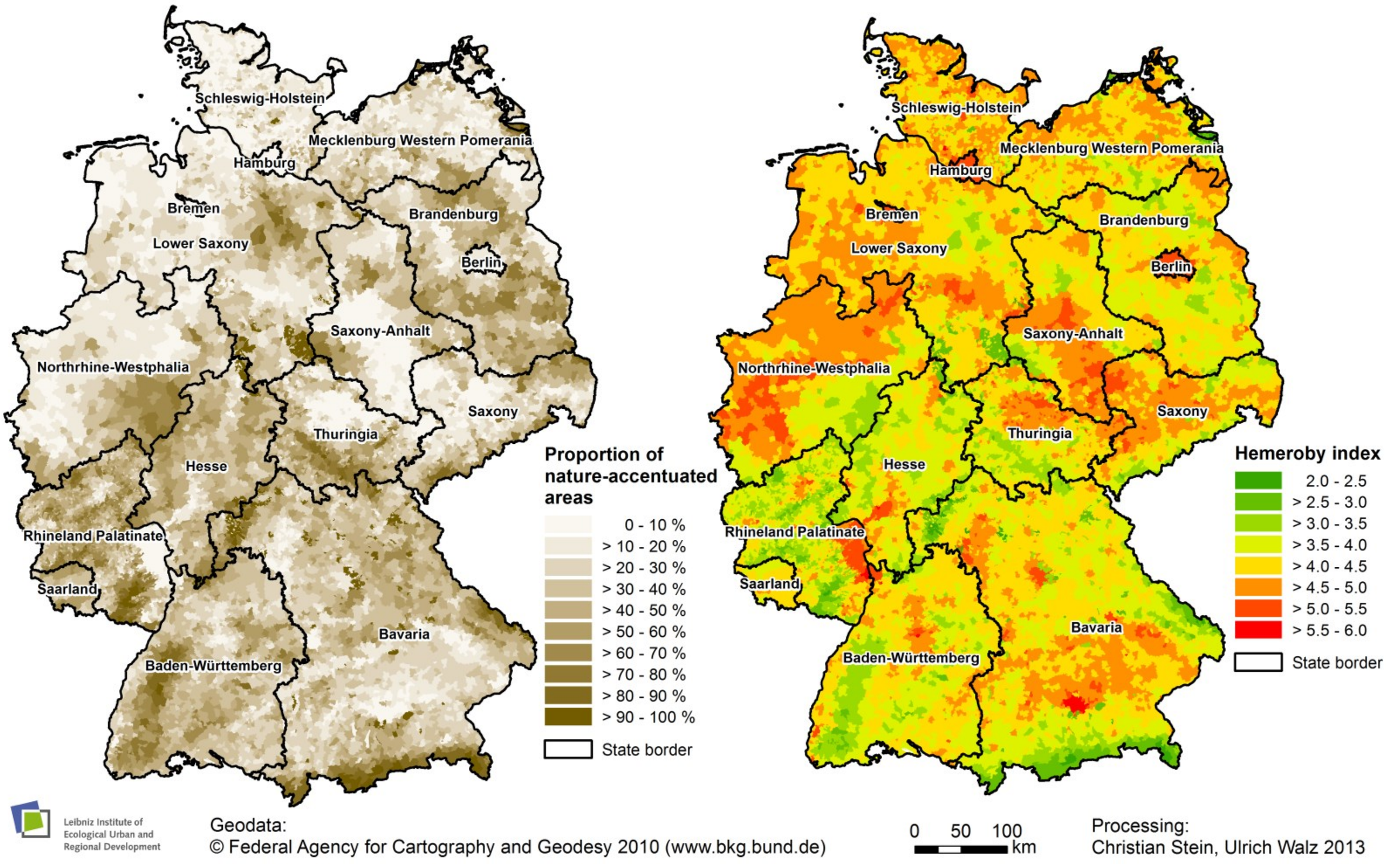

Fig. 3. Landscape hemeroby based on calculations for administrative units (municipalities) (left: proportion of nature-accentuated areas, right: hemeroby index) (processing:C. Stein and U. Walz).

Table 3
Proportion of nature-accentuated areas in the Germany's federal states (evaluation based on municipalities).

Germany's federal states	Proportion of nature-accentuated areas as % of total surface area									
	0–10%	>10–20%	>20–30%	>30–40%	>40–50%	>50–60%	>60–70%	>70–80%	>80–90%	>90–100%
Baden-Württemberg	1.3	7.4	20.8	27.3	18.8	10.2	7.2	3.4	3.0	0.6
Bavaria	5.2	13.0	22.7	22.0	15.6	7.8	3.7	2.4	3.2	4.5
Berlin	0	100	0	0	0	0	0	0	0	0
Brandenburg	7.1	8.9	18.9	16.7	20.1	11.2	11.7	4.9	0.4	0
Bremen	100	0	0	0	0	0	0	0	0	0
Hamburg	100	0	0	0	0	0	0	0	0	0
Hesse	2.6	5.1	13.4	24.4	25.3	17.8	7.3	2.3	0.3	1.5
Mecklenburg-Western Pomerania	14.6	33.6	21.1	11.5	7.3	5.7	3.4	1.9	0.5	0.4
Lower Saxony	19.1	29.6	21.8	14.0	6.1	2.8	2.2	1.1	0.9	2.4
North Rhine-Westphalia	15.3	37.1	13.6	8.7	7.6	8.9	5.9	2.8	0.0	0.0
Rhineland-Palatinate	10.2	5.7	11.9	15.3	18.7	12.9	11.4	8.4	3.8	1.6
Saarland	0	3.0	18.2	33.4	7.0	32.2	6.2	0	0	0
Saxony	17.9	22.9	20.6	11.9	9.0	7.3	4.1	4.1	2.1	0
Saxony-Anhalt	30.5	17.6	14.5	15.4	11.1	5.3	2.4	2.8	0.4	0
Schleswig-Holstein	45.4	29.7	14.5	6.0	1.6	0.7	1.0	0.1	0.1	0.9
Thuringia	19.4	10.2	14.0	18.5	12.8	10.0	6.3	5.6	2.7	0.3

Table 4

Proportion of landscape hemeroby index classes in Germany's federal states (evaluation based on municipalities).

Germany's federal states	Proportion of landscape hemeroby index classes as % of the total surface area							
	2.0–2.5	>2.5–3.0	>3.0–3.5	>3.5–4.0	>4.0–4.5	>4.5–5.0	>5.0–5.5	>5.5
Baden-Württemberg	0	1.3	14.6	31.9	41.2	9.5	1.3	0.1
Bavaria	1.2	5.9	7.8	27.5	37.5	17.7	1.9	0.5
Berlin	0	0	0	0	0	0	100	0
Brandenburg	0.0	0.0	6.5	35.6	43.7	13.7	0.5	0.01
Bremen	0	0	0	0	0	21.0	79.0	0
Hamburg	0	0	0	0	0	0	100	0
Hesse	0	2.1	15.5	48.7	24.0	7.5	2.2	0.1
Mecklenburg-Western Pomerania	0.5	1.3	4.7	16.9	46.5	30.0	0.1	0
Lower Saxony	0.1	2.2	2.7	9.4	51.8	31.7	2.0	0
North Rhine-Westphalia	0	0	6.0	20.5	17.1	43.6	12.7	0.2
Rhineland-Palatinate	0.2	7.5	23.4	34.4	19.8	7.7	6.8	0.4
Saarland	0	0	0	24.6	67.5	7.9	0	0
Saxony	0	0.1	7.4	18.5	29.2	39.9	4.8	0
Saxony-Anhalt	0	0	5.8	15.3	37.7	34.0	7.1	0
Schleswig-Holstein	0.2	1.0	1.0	7.1	48.8	38.9	2.9	0.2
Thuringia	0.1	1.0	12.6	28.8	29.5	23.9	4.2	0

Discussion

Why do we need further indicators?

Up to now the development of open space in Germany has been quantitatively evaluated within the National Strategy on Biological Diversity by means of an indicator on land consumption (increase in settlement and traffic areas) (BMU 2010). In this case the monitoring of change only takes account of the proportionate development of residential and traffic areas. This indicator describes the general development of land area for housing and transport. However, it provides no information on the forms of land use of areas which are negatively affected, and also gives no indication of how the state of the landscape as a whole is changing in relation to the impact of other land use changes. In contrast, the hemeroby index covers the cumulative impact of such diverse land use changes. For example, if in addition to changes in settlement and transport areas, agricultural use has also undergone some form of transition (e.g. meadows transformed into arable land) then all these factors are reflected by the indicator. Compensatory measures are also taken into account. For example, if the consumption of land for new roadways is off-set by reforestation measures elsewhere, these balancing factors will be incorporated in the hemeroby index (Stein & Walz 2012). There is a need for comprehensive and nationwide environmental indicators, e.g. for the assessment of the likely environmental effects of plans and programs like the German federal transport infrastructure plan (Wende et al. 2004: p. 120).

Furthermore, the hemeroby index allows conclusions on biodiversity. Kowarik (1988: p. 118) showed for West-Berlin that a low to moderate human impact promotes plant species richness, while a strong impact reduces the diversity of plants species. In mesohemerobic areas most plant species could be found. With increasing human impact rare species are displaced and common plant species are promoted (Kowarik 1988: p. 138).

Beyond this background, the two proposed indicators have different focal points: while at the municipal level the hemeroby index represents an average value of the human impact, the focus when looking at the proportion of nature-accentuated areas is on areas of value for nature conservation.

Comparison to other evaluations of hemeroby

In comparison to other evaluations of hemeroby in other regions, our method is based on assessment of land use units at the landscape level, while a lot of earlier studies are based directly on vegetation data (Jansen et al. 2009; Klotz & Kühn 2002; Schlüter 1984). Instead of spatial types (Glawion 2002) or whole landscapes (Wrbka et al. 2005: p. 45), we classified detailed land use units. The advantage of our method is that the concept could be applied for larger regions, in our case the whole of Germany. Furthermore it is easy to calculate and to understand, which is important for regular monitoring and the dissemination of the results to the public.

Earlier methods based on CORINE (25 ha) (Brentrup et al. 2002; Cscorba & Szabó 2009; Glawion 2002; Paracchini & Capitani 2011; Rüdisser et al. 2012) or maps of biotope types of federal states (LfULG 2009) are not useful for a detailed Germany-wide monitoring of hemeroby on the level of municipalities or grid cells. Main reasons are the coarse scale of data, the lack of coverage for the whole of Germany or that the regular repletion of data acquisition is not given. Therefore, we have developed a new method using DLM-DE (1 ha).

Problems of differentiation in forest and grassland

Although the DLM-DE is one of the most detailed datasets of land use for the whole of Germany, the modeling of forest and grassland is rather generalised. Yet in comparison to the Basis-DLM, forests in the DLM-DE are modeled at greater spatial detail and with more frequent updating. Nevertheless, forests are only classified as deciduous, coniferous or mixed forest, and there is no possibility of distinguishing between the different levels of intensity of grassland use. Here the mapping of biotope types could provide more accurate results. Unfortunately, such data is currently unavailable for the whole of Germany.

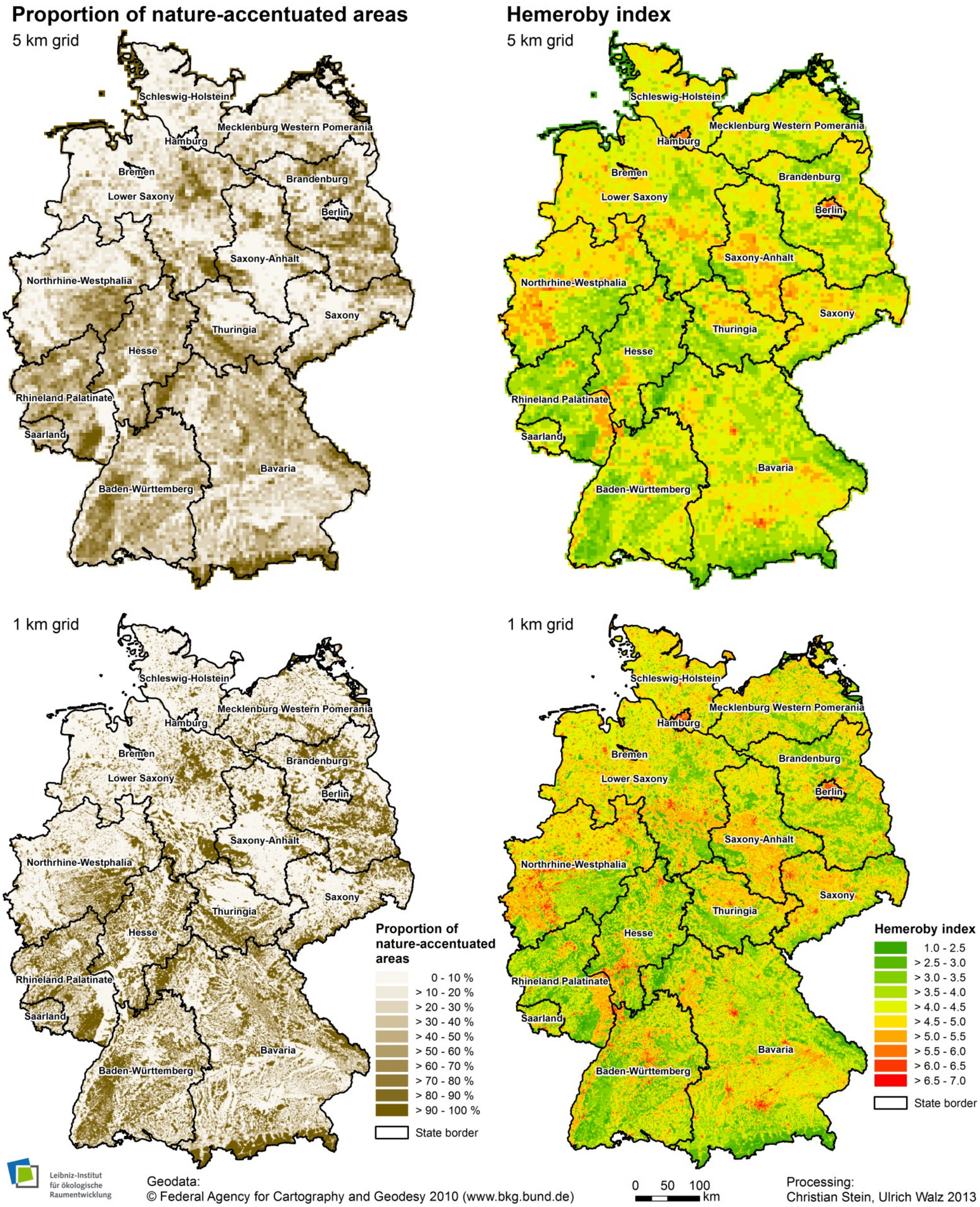

Fig. 4. Landscape hemeroby based on calculations for grid cells (left: proportion of nature-accentuated areas, right: hemeroby index; top: grid size of 5 km, bottom: grid sizeof 1 km) (processing: C. Stein and U. Walz).

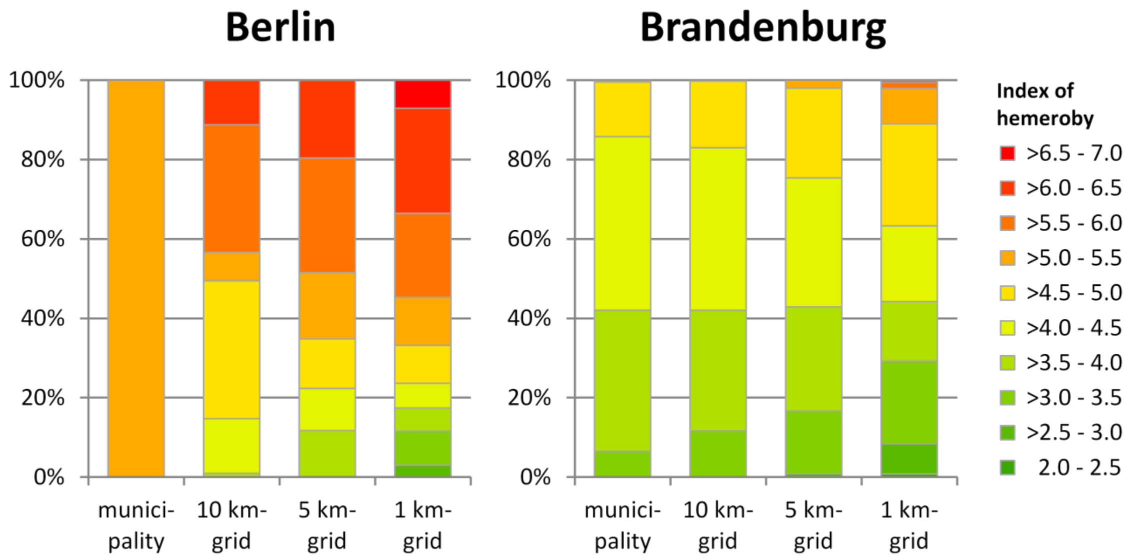

Fig. 5. Proportion of hemeroby index classes to total area, depending on the chosen reference unit (processing: C. Stein and U. Walz).

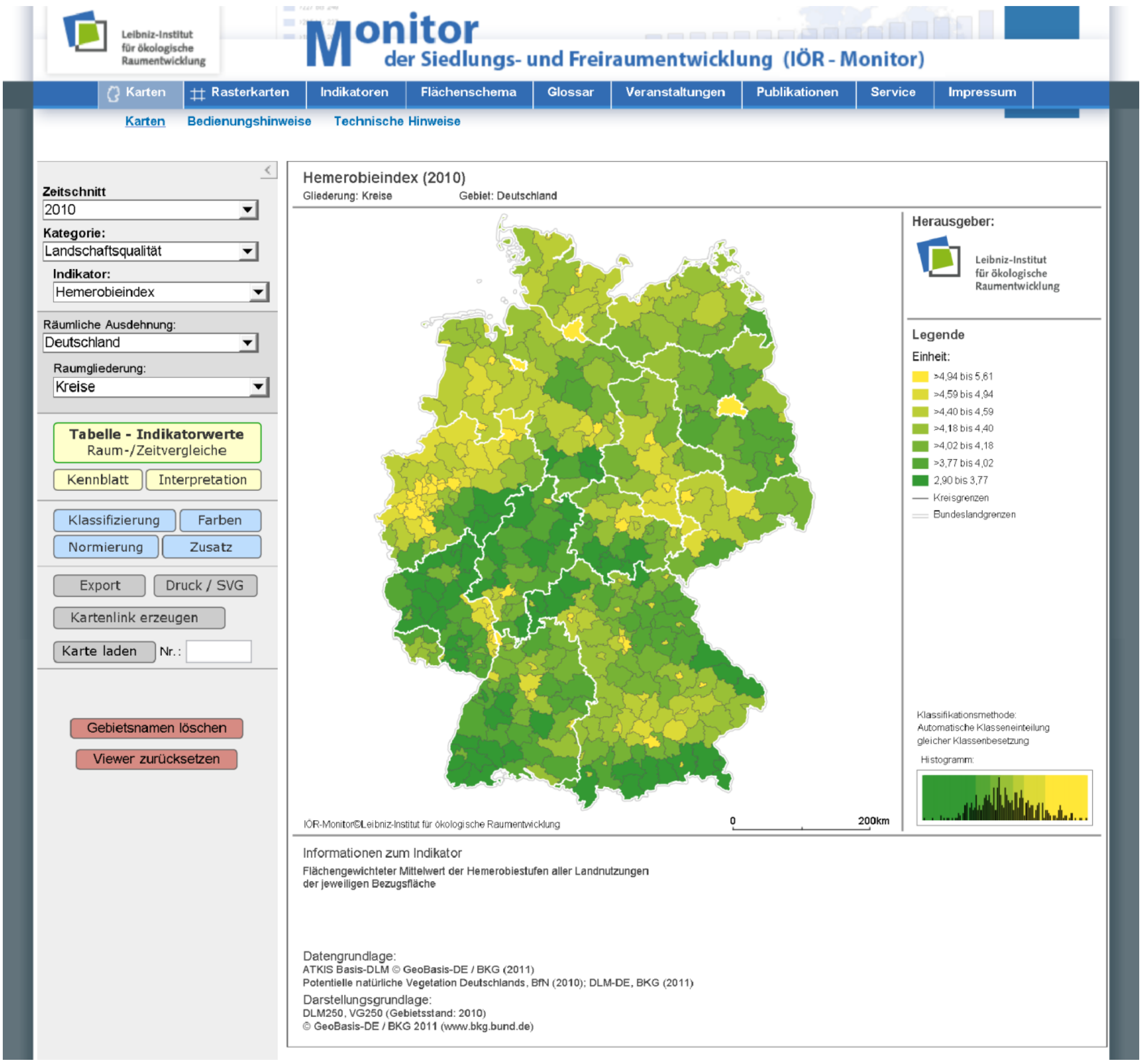

Fig. 6. Screenshot of the website on the landscape hemeroby index based on administrative units (district) within the IOER-Monitor of Settlement and Open Space Development, www.ioer-monitor.de.

A comparative calculation based on the biotope type mapping of Saxony from 2005 has shown that in the Basis-DLM, forests were generally evaluated as rather close to nature, while a higher degree of hemeroby was assigned to grassland (Stein 2011). This is because grassland in Basis-DLM is simply assumed to be intensively used grassland, while the lack of attributes to describe forests (such as age, structure of the stock and composition of species) prevent any conclusions being drawn on the type and intensity of forest use. It is therefore impossible, on the basis of the Basis-DLM or the DLM-DE, to assign, e.g. similarly aged monocultural forests of non-native tree species to the degree of β-euhemerobic. Consequently, site-adapted forests were categorised as oligohemerobic, non-adapted tree stocks as mesohemerobic forests and woodlands within settlements as β-euhemerobic.

Administrative units versus grid cells

The choice of reference unit greatly affects the calculation of indicators: the smaller the chosen grid, the more highly differentiated the resulting analysis. The information gain achieved if a uniform grid is applied instead of simply adopting standard municipal boundaries can be illustrated in the case of Berlin. At the municipal level, Berlin as a whole achieves a hemeroby index value of 5.28, and yet increased differentiation of results is already apparent when applying the 10 km grid (see Fig. 5). This effect occurs in all other federal states. Most importantly, application of a grid removes the influence of administrative unit size on results.

Nevertheless, the calculation of indicator values at the municipal level can be useful, especially in relation to spatial planning, which is usually based on administrative units. There is also no objection to their use for the periodic comparison of levels of development. As emphasised at the beginning, the temporal comparison is in the foreground in the evaluation of hemeroby. In any case, a 1 km grid should certainly be adopted if an analysis is required at a high degree of spatial differentiation. Nevertheless, since the hemeroby of landscape should be considered, grid sizes less than 1 km^2 seems less useful because otherwise nearly individual objects are mapped.

Conclusions and outlook

Our outcomes show, that it is possible to estimate and compare human impact on the landscape level for the whole of Germany at different spatial and temporal levels of reference. With the DLM-DE and ATKIS a sufficient data base is available for regular monitoring of hemeroby at the landscape level. However, some generalisations are necessary, the results show that a German-wide monitoring will be able to represent changes in human impacts in sufficient accuracy and detail up to the levels of municipalities or 1 km grid cells.

We were also able to show, that the results could be integrated in a nationwide monitoring system. The calculated indicators of hemeroby for 2010 are freely available from the IOER-Monitor in the form of maps and tables (Meinel et al. 2013), and can be processed by any third party (see Fig. 6). With the delivery of the next actual dataset of DLM-DE in 2014 it will be possible to calculate a second time step. Therefore the main outcome of this research will be the establishment of a regular monitoring of hemeroby in Germany.

Indicators of hemeroby can be a meaningful supplement to information provided by other national indicator systems, e.g. the indicator “Species diversity and landscape quality” in the National Strategy on Biological Diversity (BMU 2010). While this indicator indirectly assesses the state of the landscape as a habitat based on the population sizes of 59 representative bird species, the concept of hemeroby evaluates the landscape state as a function of overall human impact.

Regarding the indicator on the development of settlement and traffic areas, e.g. of the National Strategy on Biological Diversity, valuable knowledge on land consumption can be obtained. The development of the share of nature-accentuated areas can indicate whether increasing utilisation of land for settlement and transport is mainly at the expense of more natural areas or those already under intensive use.

Human impacts on the landscape for each municipality, district or province could be monitored by examining the trends overtime of hemeroby indices or the proportion of nature-accentuated areas. In combination with other indicators and parameters such as landscape fragmentation, the proportion of landscape and nature conservation areas or population trends of certain species, valuable insights can be gained on the development of open spaces. Other interesting questions could be examined, such as a potential association between the rehabilitation of endangered species and the hemeroby of the landscape.

Regular calculation of the presented indicators could make a significant contribution to the qualitative description of settlement and open space development in Germany. It would supply decision-makers and the interested public with detailed information on the changes taking place in landscapes, while at the same time high-lighting the responsible use of open space. The indicators can reveal deficiencies within nature protection and landscape planning, pin-pointing where measures to improve the condition of landscape are especially needed, while at the same time drawing attention to positive developments.

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References

Arnold, S. (2009). Digital landscape model DLM-DE – Deriving land cover information by integration of topographic reference data with remote sensing data. ISPRS Archives,. XXXVIII-1-4-7/W5

BfN – Bundesamt für Naturschutz. (2010). Karte der potentiellen natürlichen Vegetation Deutschlands. Maßstab 1:500.000 [Map of potential natural vegetation in Germany. Scale 1:500.000]. Bonn-Bad Godesberg

Blume, H.-P., & Sukopp, H. (1976). Ökologische Bedeutung anthropogener Bodenveränderungen, [Ecological significance of anthropogenic soil changes].Schriftenreihe für Vegetationskunde, 10, 75–89.

BMU – Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. (2010). Indicator report 2010 to the National Strategy on Biological Diversity. Berlin.

Brentrup, F., Küsters, J., Lammel, J., & Kuhlmann, H. (2002). Life cycle impact assessment of land use based on the hemeroby concept. International Journal of Life Cycle Assessment, 7, 339–348.

Cscorba, P., & Szabó, S. (2009). Degree of human transformation of landscapes: A case study from Hungary. Hungarian Geographical Bulletin, 58(2), 91–99.

Dramstad, W. E., Tveit, M. S., Fjellstad, W. J., & Fry, G. L. A. (2006). Relationships between visual landscape preferences and map-based indicators of landscape structure. Landscape and Urban Planning, 78(4), 465–474.

Dröschmeister, R. (2000). Conceptual requirements on monitoring for nature conservation at a European level. In C. Bischoff, & R. Dröschmeister (Eds.), Schriftenreihe für Landschaftspflege und Naturschutz (Vol. 62) European monitoring for nature conservation. Proceedings of the international symposium on monitoring for nature conservation at a European level, Isle of Vilm, Germany, 1–5 March 1999 (pp. 7–19). Münster: Landwirtschaftsverlag.

EEA – European Environment Agency. (2000). CORINE land cover technical guide– addendum 2000. Technical report, 40. Copenhagen. http://image2000.jrc.it/reports/corine_tech_guide_add.pdf (13.02.14)

European Commission, Eurostat. (2005). Short proceedings of Euro Grid workshop: Working document for the meeting of the working party “Geographical Information Systems for Statistics”. Luxemburg (E/GIS/79/EN).

Federal Agency for Cartography and Geodesy. (2011). Digital base landscape model: Basis-DLM. Frankfurt a. M.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). (2007). National Strategy on Biological Diversity: Adopted by the Federal Cabinet on 7 November 2007. Environmental Policy Series. Bonn.

Federal Statistical Office of Germany. (2012). Sustainable development in Germany: Indicator report 2012. Wiesbaden.

Frank, S., Fürst, C., Koschke, L., & Makeschin, F. (2012). A contribution towards a transfer of the ecosystem service concept to landscape planning using landscape metrics. Ecological Indicators, 21, 30–38.

Fu, B.-J., Hu, C.-X., Chen, L.-D., Honnay, O., & Gulinck, H. (2006). Evaluating change in agricultural landscape pattern between 1980 and 2000 in the Loess hilly region of Ansai County, China. Agriculture, Ecosystems and Environment, 114, 387–396.

Glawion, R. (2002). Ökosysteme und Landnutzung, [Ecosystems and land use]. In H.Liedtke, & J. Marcinek (Eds.), Physische Geographie Deutschlands, [Physical geography of Germany] (Perthes Geographie Kolleg, 3rd ed., Vol. 62, pp. 289–319).Gotha: Klett.

Grabherr, G., Koch, G., Kirchmeier, H., & Reiter, K. (1998). Hemerobie österreichischer Waldökosysteme, [Hemeroby of Austrian forest ecosystem]. Veröffentlichungen des Österreichischen MaB-Programms, 17. Innsbruck.

Hellawell, J. M. (1991). Development of a rationale for monitoring. In B. Goldsmith(Ed.), Monitoring for conservation and ecology (pp. 1–14). London: Chapman &Hall.

INSPIRE – Infrastructure for Spatial Information in Europe. (2010). D2.8.I.2 INSPIRE specification on geographical grid systems – Guidelines.

Jalas, J. (1955). Hemerobe und hemerochore Pflanzenarten. Ein terminologischer Reformversuch, [Hemerobic and hemerochoric and plant species. An attempt of a terminological reform]. Acta Societatis pro Fauna et Flora Fennica, 72, 1–15.

Jansen, F., Zerbe, S., & Succow, M. (2009). Changes in landscape naturalness derived from a historical land register – A case study from NE Germany. Landscape Ecology, 24(2), 185–198.

Jedicke, E. (2003). Natur oder Kunstnatur? – Naturnähe und Hemerobie, [Nature or artificial nature? Naturalness and hemeroby]. In Leibniz-Institut für Länderkunde (Ed.), Nationalatlas Bundesrepublik Deutschland. Klima, Pflanzen- und Tierwelt (1st ed., pp. 28–29). Heidelberg, Berlin: Spektrum Akademischer Verlag.

Keil, M., Bock, M., Esch, T., Metz, A., Nieland, S., & Pfitzner, A. (2010). CORINE Land Cover Aktualisierung 2006 für Deutschland, Abschlussbericht [CORINE Land Cover 2006 update for Germany, Final Report]. Wessling: Deutsches Zentrum für Luft- und Raumfahrt e.V.; Deutsches Fernerkundungsdatenzentrum Oberpfaffenhofen.

Kieser, A., & Thannheiser, D. (2001). Erfassung der Naturnähe und ortstypischer Flächennutzungen im Siedlungsbereich. Fallbeispiele zu Hemerobie und Nutzungsstrukturen, [Degree of naturalness and typical land use types in settled areas – examples on hemeroby and land use structures]. Naturschutz undLandschaftsplanung, 33, 150–156.

Klotz, S., & Kühn, I. (2002). Indikatoren des anthropogenen Einflusses auf die Vegetation [Indicators of anthropogenic influence on vegetation]. Schriftenreihe für Vegetationskunde, 38, 241–246.

Konnert, V., & Siegrist, J. (2000). Waldentwicklung im Nationalpark Berchtesgaden von 1983 bis 1997: Gemeinsame Auswertung der 1 und 2. Permanenten Stichproben-Inventur [Forest development in Berchtesgaden National Park from 1983 to 1997]. Forschungsbericht des Nationalpark Berchtesgaden, 43.

Kowarik, I. (1988). Zum menschlichen Einfluss auf Flora und Vegetation: Theoretische Konzepte und ein Quantifizierungsansatz am Beispiel von Berlin (West), [To the human impact on flora and vegetation: Theoretical concepts and a quantification approach using the example of Berlin (West)]. Landschaftsentwicklung und Umweltforschung, 56, 1–280.

Kowarik, I. (2006). Natürlichkeit, Naturnähe und Hemerobie als Bewertungskriterien, [Naturalness, closeness to nature and hemeroby as evaluation criteria]. In O. Fränzle, F. Müller, & W. Schröder (Eds.), Handbuch der Umweltwissenschaften:Grundlagen und Anwendungen der Ökosystemforschung (Vol. 16). Weinheim:Wiley-VCH. Erg. Lfg.: V.I.3-12.

Kowarik, I., Bartz, R., & Heink, U. (2008). Bewertung “ökologischer Schäden” infolge des Anbaus gentechnisch veränderter Organismen (GVO) in der Landwirtschaft, [Assessment of “ecological damages” as a result of the cultivation of genetically modified organisms (GMOs) in agriculture].

Naturschutz und Biologische Vielfalt (Vol. 56) Bonn-Bad Godesberg: Bundesamt für Naturschutz.
LfULG – Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie. (2009). Hemerobie der Biotop- und Landnutzungstypen, [Hemeroby of habitat and land usetypes]. http://www.umwelt.sachsen.de/umwelt/natur/26261.htm (13.02.14)
Machado, A. (2004). An index of naturalness. Journal for Nature Conservation, 12, 95–110.
Marks, R., & Schulte, W. (1988). Anthropogene Einflüsse, [Anthropogenic influences]. In H. Leser, & H.-J. Klink (Eds.). Handbuch und Kartieranleitung Geoökologische Karte 1:25.000 (KA GÖK 25), [Manual and mapping instructions for the geoecological map]. Forschungen zur deutschen Landeskunde, 228, 213–226.Trier.
Meinel, G. (2009). Konzept eines Monitors der Siedlungs- und Freiraumentwicklung auf Grundlage von Geobasisdaten, [Concept of a monitor of settlement and open space development on the basis of official geodata]. In G. Meinel, & U. Schumacher (Eds.), Flächennutzungsmonitoring. Konzepte – Indikatoren – Statistik, Land use monitoring. Concepts – indicators – statistics (pp. 177–194). Aachen: Shaker.
Meinel, G., Krüger, T., Schumacher, U., Hennersdorf, J., Förster, J., Köhler, C., Walz, U. & Stein, C. (2013). Flächennutzungsmonitoring – aktuelle Ergebnisse und Entwicklungen im IÖR-Monitor, [Land use monitoring – New results within the IOER-Monitor]. In G. Meinel, U. Schumacher, & M. Behnisch (Eds.), FlächennutzungsmonitoringV, Methodik – Analyseergebnisse – Flächenmanagement, Land use monitoring V, methodology – analysis results – land management (pp. 117–129). Berlin: Rhombos.
Paracchini, M. L., & Capitani, C. (2011). Implementation of a EU wide indicator for the rural-agrarian landscape. JRC scientific and technical reports (EUR 25114 EN-2011).Luxembourg: Publications Office of the European Union.
Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E.,et al. (2004). Evaluating the ecological sustainability of Austrian agricultural landscapes – The SINUS approach. Land Use and Sustainability Indicators, 21,307–320.
Rüdisser, J., Tasser, E., & Tappeiner, U. (2012). Distance to nature – A new biodiversity relevant environmental indicator set at the landscape level. Ecological Indicators, 15, 208–216.
Schlüter, H. (1984). Kennzeichnung und Bewertung des Natürlichkeitsgrades derVegetation [Identification and assessment of the degree of naturalness of vegetation]. Acta Botanica Slovaca, Series A: Taxonomica Geobotanica, (Suppl. 1), 277–283.
Schlüter, H. (1992). Vegetationsökologische Analyse der Flächennutzungsmosaike Nordostdeutschlands. Natürlichkeitsgrad der Vegetation in den neuen Bundesländern, Vegetation ecological analysis of land use mosaics in East Germany. Naturalness of the vegetation in the new federal states. Naturschutz und Landschaftsplanung, 24(5), 173–180.
Schumacher, U., & Meinel, G. (2009). ATKIS, ALK(IS), Orthobild – Vergleich von Datengrundlagen eines Flächenmonitorings, [ATKIS, ALK (IS), ortho-image – Comparison of data bases of a spatial monitoring]. In G. Meinel, & U. Schumacher (Eds.), Flächennutzungsmonitoring. Konzepte – Indikatoren – Statistik, [Land use monitoring. Concepts – indicators – statistics] (pp. 47–67). Aachen: Shaker.
Stein, C. (2011). Hemerobie als Indikator zur Landschaftsbewertung – eine GIS-gestützte Analyse für den Freistaat Sachsen, [Hemeroby as an indicator for landscape assessment – A GIS-based analysis for the Free State of Saxony] (Diploma thesis). Philipps-University of Marburg. http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-129355
Stein, C., & Walz, U. (2012). Hemerobie als Indikator für das Flächenmonitoring. Methodenentwicklung am Beispiel von Sachsen, [Hemeroby as indicator for the monitoring of land use – Development of methods using the example of Saxony].Naturschutz und Landschaftsplanung, 44, 261–266.
Steinhardt, U., Herzog, F., Lausch, A., Müller, E., & Lehmann, S. (1999). The hemeroby index for landscape monitoring and evaluation. In D. E. Hyatt, R. Lenz, & Y. A. Pykh (Eds.), Environmental indices systems analysis approach. Advances in sustainable development. Proceedings of the first international conference on environmental indices systems analysis approach (INDEX-97), St. Petersburg, Russia, July 7–11, 1997 (pp. 237–254). Oxford: EOLSS.
Sukopp, H. (1969). Der Einfluss des Menschen auf die Vegetation, [Human impact on the vegetation]. Vegetatio, 17, 360–371.
Sukopp, H. (1972). Wandel von Flora und Vegetation in Mitteleuropa unter dem Einfluß des Menschen, [Change of flora and vegetation in central Europe under human impact]. Berichte über Landwirtschaft, 50, 112–139.
Sukopp, H. (1976). Dynamik und Konstanz in der Flora der Bundesrepublik Deutschland, [Dynamics and stability in Flora of the Federal Republic of Germany].Schriftenreihe für Vegetationskunde, (10), 9–26.
Tasser, E., Sternbach, E., & Tappeiner, U. (2008). Biodiversity indicators for sustainability monitoring at municipality level: An example of implementation in an alpine region. Ecological Indicators, 8, 204–223.
Tüxen, R. (1956). Die heutige potentielle natürliche 620 Vegetation als Gegenstand der Vegetationskartierung [The current potential natural vegetation as a subject of vegetation mapping. Angewandte Pflanzensoziologie, 13, 5–42.
Wende, W., Hanusch, M., Gassner, E., Guennewig, D., Koeppel, J., Lambrecht, H., et al. (2004). Requirements of the SEA directive and the German federal transport infrastructure plan. European Environment, 14, 105–122.
Wonka, E. (2009). Flächenstatistik und Datengrundlagen nach regionalstatistischen Rastereinheiten in Österreich [Area statistics and data bases for regional statistical grid units in Austria]. In G. Meinel, & U. Schumacher (Eds.), Flächennutzungsmonitoring. Konzepte – Indikatoren – Statistik, Land use monitoring. Concepts – indicators – statistics (pp. 155–175). Aachen: Shaker.
Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany. (2009). Documentation on the modelling of geoinformation of official surveying and mapping (GeoInfoDoc): Main document version 6.0.1.
Wrbka, T., Erb, K.-H., Schulz, N. B., Peterseil, J., Hahn, C., & Haberl, H. (2004). Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. Land Use Policy, 21, 289–306.
Wrbka, T., Reiter, K., Paar, M., Szerencsits, E., Stocker-Kiss, A., & Fussenegger, K. (2005). Die Landschaften Österreichs und ihre Bedeutung für die biologische Vielfalt, [The landscapes of Austria and their importance for biodiversity]. Monographien des Umweltbundesamtes,. M-173, Wien.